CHAPTER 13.—METHANE CONTROL IN METAL/NONMETAL MINES

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This chapter gives guidelines for preventing methane gas explosions during metal and nonmetal mine development and subsequent production operations.[3] Emphasis is placed on recognizing the differences between coal mines, where the potential for methane hazards is relatively well understood, and metal/nonmetal mines, where methane may accumulate unexpectedly. Also, interviews with experienced mine operators add much to a complete understanding of what must be done to address methane problems in metal/nonmetal mines.

METHANE GAS IN METAL/NONMETAL MINES

Gas reports from around the world. The presence of methane gas in metal/nonmetal mines around the world is more common than one might imagine [Edwards and Durucan 1991]. For example:

- The former Soviet republics have occurrences of methane and hydrogen in apatite, gold, and diamond ores, where solid or liquid bitumen occurs in the rock.

- Scandinavian iron ore deposits include methane and other hydrocarbons in boreholes that intersect pitch and asphalt within the deposits, and methane and nitrogen in boreholes and fissures in arsenic and sulfide ores.

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[3]Those mines extracting metallic ores such as copper or nickel are referred to as "metal mines." Those mines extracting nonmetallic minerals such as salt, potash, trona, and limestone are referred to as "nonmetal mines."

- In Eastern Europe, petroleum and gas has been observed in igneous and metamorphic rocks in Yugoslavia, in some copper mines in Hungary, and in mica schists containing limestone intrusions in Romania.

- In the United Kingdom, granites in Cornwall and Aberdeen and iron ore deposits in Cleveland all report hydrocarbon gases associated with overlying bituminous shales. Also, Derbyshire lead mines have reported methane along with bitumen.

- Canadian Shield mines contain methane, other hydrocarbons, and sometimes hydrogen and helium [Fritz et al. 1987; Andrews 1987]. These are widespread and occur in almost all the mines, particularly where carbonaceous materials are found in the rocks. The emissions are usually associated with boreholes [Sherwood et al. 1988] and are relatively short-lived and easily dissipated. The Kidd Creek mines have methane pockets associated with sulfide deposits. At some mines, the occurrences of methane and hydrogen increase with depth, and the resulting gas mixtures reduce the lower explosive limit to as low as 4.5%.[4] The Ontario Ministry of Labour (OML) has approximately eight reports per year of combustible gas in an underground working place [OML 1996]. These reports are almost always for boreholes, with measured concentrations of 0.1%–10%. Gas is very seldom detected in the general body of the mine's atmosphere, although methane ignitions due to cigarette smoking and friction between metal and sandstone have been reported to the OML.

- U.S. mines report methane emissions associated with oil shales, salt, trona, potash, limestone, copper, and uranium ores.

- In Australia, hydrocarbon gases are reported from copper mines and from Precambrian rocks at Kalgoorlie. The usual type of methane encounter is a diamond drill blower and methane is readily dispersed.

- The Republic of South Africa has combustible gases in almost all gold and platinum mines, as well as kimberlite pipes. Along with the methane, there can be hydrogen and helium. The usual assumption is that the methane is associated with overlying Karoo strata, which are coal-bearing [Searra 1990; Eschenburg 1980; Jackson 1957]. The gas is transported downward through the rock dissolved in water.

REGULATIONS FOR GASSY METAL/NONMETAL MINES IN THE UNITED STATES

The United States developed new federal standards for controlling methane hazards in metal/nonmetal mines in 1985. These are contained in 30 CFR[5] 57, Subpart T—Safety Standards for Methane in Metal and Nonmetal Mines. Considering that there is such a wide variety of metal/nonmetal mines in the United States, these standards are quite comprehensive and detailed.

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[4]For more information on the lower explosive limit, see Chapter 1.
[5]*Code of Federal Regulations*. See CFR in references.

Because of this, any discussion of controlling methane must first begin with a discussion of the regulations and their history.

The impetus for the revision to the standard, which previously had been based on the simple observation and measurement of methane in the mine atmosphere, was the Belle Isle Mine disaster of 1979 [Plimpton et al. 1979]. The Belle Isle Mine was an underground salt mine in a salt dome in southern Louisiana. The salt domes are known for their proximity to petroleum production facilities, with oil and gas often found in the sedimentary structures adjacent to the sides of the up-thrusting salt domes. The mine had produced gas intermittently for many years since it was opened in 1962. There had also been "outbursts"[6] of salt found after regular production blasts. What was not understood at the time was the mechanism for the release of huge quantities of methane gas from these outbursts. When postblast crew members went down into the mine after a blast at Belle Isle, an ignition source, possibly the diesel pickup truck that they were riding in, set off a massive explosion, killing all five members of the crew underground at the time.

Earlier, a gas explosion at the Cane Creek potash mine in Utah had occurred in 1963 wherein 18 miners were killed during development operations [Westfield et al. 1963]. Several of these miners survived the initial explosion itself, only to die in a barricaded dead-end drift when their oxygen supply ran out.

Significantly, neither Belle Isle Mine nor Cane Creek Mine had reached the threshold of 0.25% methane in the general atmosphere of the mine (as required by the regulations of the time). Therefore, neither was considered to be a "gassy mine."

There is a wide variety of metal/nonmetal mines, with many different ways in which methane is released into the mine atmosphere. To address the numerous mine-specific potential methane hazards, the Mine Safety and Health Administration (MSHA) defined various categories of gassy mines (30 CFR 57.22003) in the 1985 federal standards, as summarized below.[7]

Category I applies to mines that operate within a combustible ore body and either liberate methane or have the potential to liberate methane. Within Category I, there are several subcategories, depending on the actual presence of methane gas (at 0.25% or more) or the occurrence of an ignition (Subcategory I–A) or not (Subcategory I–B). Subcategory I–C is intended to include the potential hazard from flammable dust. Category I applies mainly to oil shale and gilsonite mines.

[6]An outburst is a sudden, violent release of solids and high-pressure occluded gases, including methane, in a domal salt mine (30 CFR 57.22002).

[7]A precedent for developing gassy mine standards in this manner that took into account the different hazards associated with differing methane gas occurrences was found in Spanish mining regulations [Lumsden and Talbot 1983].

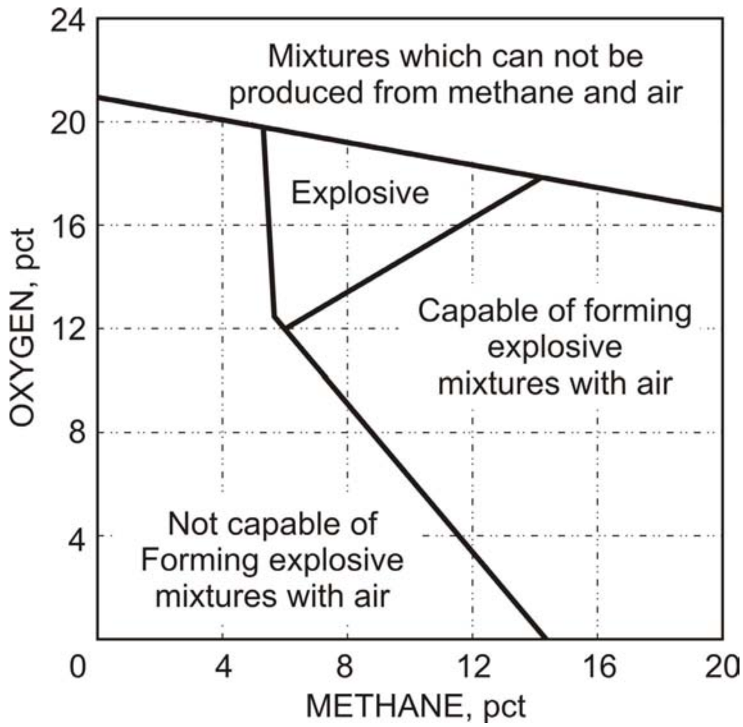

Figure 13–1.—Relation between quantitative composition and explosibility of mixtures of methane and air (from 30 CFR 57.22003(3)).

Category II applies to domal salt mines where the history of the mine or geological area indicates the occurrence of or potential for an outburst. As with Category I, there are two subcategories, depending on the occurrence of an outburst that released 0.25% or more of methane (Subcategory II–A) or not (Subcategory II–B).

Category III applies to mines in which noncombustible ore is extracted and which liberate a concentration of methane that is explosive, or is capable of forming explosive mixtures with air, or has the potential to do so based on the history of the mine or the geological area in which the mine is located. The flammability of the gas is determined by its position on Figure 13–1, an illustration contained at 30 CFR 57.22003(a)(3). Category III applies mainly to trona mines.

Category IV applies to mines in which noncombustible ore is extracted and which liberate a concentration of methane that is not explosive or capable of forming explosive mixtures with air. This somewhat unusual concept derives from the fact that New Mexico potash mines have methane contained within the clay and shale seams in the strata along with high percentages of inert nitrogen. The flammability of this gas mixture is determined by its position on Figure 13–1. Category IV applies mainly to potash mines.

Category V applies mainly to petroleum mines.

All mines that are not placed in any of the above categories or subcategories are considered to be *Category VI*, or nongassy, mines.

Each category (or industry sector) has its own set of requirements for monitoring and control measures. Categories I, III, and V most closely match coal mining standards, with fully permissible equipment in production settings. Category II recognizes that gas is only likely to be liberated in hazardous quantities during drilling, cutting, and blasting, so those activities are controlled. Category IV has few limitations, with monitoring of gas being the primary requirement.

DEALING WITH METHANE IN METAL/NONMETAL MINES

Dealing with methane in metal/nonmetal mines requires an understanding of five important issues:

1. **The differences between coal mines and metal/nonmetal mines, and recognizing why explosions happen even with low gas emission rates.**
2. **How to monitor for gas and what gas concentrations require action.**
3. **The importance of continuously diluting methane with ventilation air.**
4. **The importance of eliminating all ignition sources.**
5. **Avoiding outburst hazards.**

Although the regulations discussed in the previous section are important to preventing methane explosions in metal/nonmetal mines, they represent only a starting point in achieving a safe mine. A broader understanding of five important issues is necessary, which are detailed below.

1. Why metal/nonmetal mines are different from coal mines. Unlike coal mines, methane emission rates in metal/nonmetal mines are not consistent. This irregularity often makes an accumulation of methane an unexpected event, and an unexpected event by definition is difficult to anticipate.[8] Methane can be detected in coal mines everywhere and almost all the time; therefore, monitoring becomes a regular pattern of activity. Ventilation controls are rigorously maintained, and large quantities of ventilation air are blown through the mine to sweep the gas away. Permissible equipment is used to minimize ignition sources, and workers are constantly on notice that coal mines are potentially dangerous places. All of these factors lead to a constant awareness of the potential methane hazard, promoting consistent efforts to reduce the risk of an ignition or explosion.

By contrast, workers in metal/nonmetal mines may never detect methane gas or only encounter it infrequently. It is easy to become complacent, testing for gas in a cursory or offhand fashion, or not even bothering to test at all. Also, the same attention to ventilation controls is lacking, with series[9] ventilation circuits and recirculation being common practices.

See Chapter 14 for a parallel discussion on ventilation controls. Poor ventilation allows for a dangerous accumulation of gas in a location where little to no gas had been previously detected.

[8]In the manufacturing industry, quality inspections have recognized the problem of unexpected events, which is why deliberately faulty parts are slipped into an inspection line to keep the inspectors on their toes.
[9]In series ventilation, the return from one working area is used as the intake to the next one downstream.

2. Monitoring for gas and taking control measures.

> **An important part of methane monitoring is knowing what control measures to take when gas is detected. The actions described here for methane testing are only a summary. For complete details, consult the Code of Federal Regulations.**

Metal/nonmetal mines with a history of gas emissions are already on notice that they have a methane problem. The U.S. regulatory standards have very specific monitoring requirements and actions to be taken depending on the category of mine and its methane history. These provide a good, commonsense approach to methane monitoring and control measures.

Those mines that liberate significant quantities of gas must monitor for it each shift in a preshift examination similar to that for coal mines (30 CFR 57.22226 and 57.22228). No testing is mandated for those mines where methane is not expected to be present, but there are action levels and prescribed actions when gas is detected at certain levels,[10] as follows:

Actions at 0.25% methane: If the mine had never before measured 0.25% or more or never had an ignition, then changes must be made to improve ventilation, and MSHA must be notified immediately.

Actions at 0.5% methane: Ventilation changes are required to reduce methane below 0.5%. In the meantime, depending on the category of mine, one or more of the following are necessary: electrical power must be deenergized, diesel equipment must be shut off or removed, and/or work must stop.

Actions at 1.0% methane: Ventilation changes are required to reduce the methane. In the meantime, depending on the category of mine, one or more of the following are necessary: all workers from the affected areas must be withdrawn except those needed to make the ventilation changes, electrical power must be deenergized, and/or diesel equipment must be shut off or removed.

All persons must be withdrawn from the mine if the 1.0% accumulation results from a main fan failure or if 1.0% is measured at a main exhaust fan.

Actions at 2.0% methane: Ventilation changes are required to reduce the methane, and all persons must be withdrawn except those necessary to make the ventilation changes. Depending on the category of mine, one or more of the following are necessary: MSHA must be informed, the methane must be reduced to below 0.5%, and/or the methane must be reduced to below 1.0%.

For all of the above scenarios, the mine category also impacts (1) the frequency and location of methane testing, (2) the use of atmospheric monitoring systems, (3) the use of methane monitors on mining equipment, and (4) whether explosion-proof electrical equipment is used, among other factors.

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[10]Keep in mind that one needs to regularly test for gas only in the mine atmosphere, not in boreholes. Chapter 2 contains more information on sampling for methane.

In Canada, Ontario has similar requirements in Section 35 of its regulations for mines and mining plants under the Ontario Occupational Health and Safety Act [1990],[11] but with a few additional features (such as the need to provide written instructions), which makes Section 35 worthwhile to read. It is reproduced in Appendix A of this chapter.

Chapter 2 gives more information on sampling for methane.

3. Diluting the gas with more ventilation. Gas only presents a flammability or explosion problem in the explosive range: 5%–15% methane. If it is diluted with sufficient air, then it ceases to be an immediate hazard. The emphasis on adequate ventilation to dilute methane is specifically mentioned by knowledgeable mining operators.

In addition to diluting methane, it is important that the potential for layering of methane gas be eliminated.[12] Thus, fans must not only add air into the general body of the mine atmosphere, but must also stir up the air within a roadway or heading. Gas can collect in cavities in the roof or in the end of an inclined ramp or at the top of a raise, and the ventilation must be directed to stir this gas up and dilute it into the body of the mine atmosphere.

In the U.S. standards for gassy metal/nonmetal mines, several sections address airflow requirements:

> 30 CFR 57.22213 – Air flow (Category III mines).—The quantity of air coursed through the last open crosscut in pairs or sets of entries, or through other ventilation openings nearest the face, shall be at least 6,000 cubic feet per minute, or 9,000 cubic feet per minute in longwall and continuous miner sections. The quantity of air across each face at a work place shall be at least 2,000 cubic feet per minute.

This standard for Category III gassy mines includes all underground trona mines. These mines may experience gas emissions on a regular basis, so the standard provides a useful guideline for quantities and for the importance of those quantities to be directed at each workplace.

Another method of specifying airflow has been adopted in the standard for oil shale mines:

> 30 CFR 57.22211 – Air flow (Category I–A mines).—The average air velocity in the last open crosscut in pairs or sets of developing entries, or through other ventilation openings nearest the face, shall be at least 40 feet per minute. The velocity of air ventilating each face at a work place shall be at least 20 feet per minute.

[11] Section 35 applies wherever mining is being carried out and methane is likely to be present.
[12] More information on controlling with methane layers is presented in Chapter 1.

These mines typically have large openings, e.g., 25 ft high by 50 ft wide, and therefore slow air velocities despite relatively large air volumes. In this case, the standard recognizes that actual air velocity, rather than the total volume of air flowing in a mine roadway, provides the necessary turbulence to remove methane gas layers. A 20 ft/min flow in a 25-ft by 50-ft roadway translates to a total air volume of 25,000 ft^3/min.[13] Obviously, a much smaller 6,000 ft^3/min is required in the trona mines, which typically have smaller roadways, say, 12 ft high by 20 ft wide. In this case, the 6,000 ft^3/min translates to a velocity of 25 ft/min.

A more general standard exists for mines experiencing gas emissions on an irregular or intermittent basis, such as salt and oil reservoir mines, along with mines containing combustible dust:

> 30 CFR 57.22212 – Air flow (I–C, II–A, and V–A mines).—Air flow across each working face shall be sufficient to carry away any accumulation of methane, smoke, fumes, and dust.

This is a "performance-oriented" standard that outlines the desired result: the airflow should "carry away any accumulation of methane." The standard does not specify exactly what airflow quantities are needed to accomplish the desired result.

The key to methane control is to dilute and render harmless the methane gas in the mine. Good ventilation is required to accomplish this.

4. Eliminating ignition sources. Electric and diesel-powered mining equipment can provide the spark to ignite a gas explosion, and if this equipment is to be used in gassy atmospheres, it must be approved by MSHA. MSHA-approved diesel equipment is designed so that no external surface gets hot enough to ignite methane.

MSHA-approved electrical equipment can take two forms. "Intrinsically safe" equipment implies that no electrical spark will have enough energy to ignite a gas mixture. An example would be portable methane detectors. The electrical circuit in these detectors is designed not to provide a spark strong enough to ignite gas. The other form of approved equipment surrounds electrical circuits with an explosion-proof box. If gas enters the box and if it is ignited by sparking inside the box, the resulting explosion is contained within the box and cannot propagate into the external atmosphere.

One of the most common forms of removing ignition sources has nothing to do with equipment. In Category II–A (mainly domal salt) mines in the United States that are considered to be outburst-prone, all blasting is done with the mine evacuated of all personnel. Only when the mine is determined to be clear of gas, using remote methane monitoring systems, are workers allowed to enter the mine to conduct a preshift examination.

[13]Air volume (ft^3/min) = Air velocity (ft/min) × roadway area (ft^2).

The most obvious ignition source has nothing to do with equipment. The thought of risking your life for a cigarette is dreadful to contemplate. Yet one of the recent U.S. mining disasters was almost certainly caused by a miner smoking in a coal mine. It takes continued vigilance by all miners to make sure that accidents like that never happen again.

Matches and other smoking materials must not be carried into mines where methane gas may be present.

5. Avoiding outburst hazards. To avoid outburst hazards in domal salt mines, continuous mining machines used in these mines should be operated only in areas that are known to be relatively gas-free. This is because methane gas trapped within the salt mass can be at high pressure. This pressure represents a source of mechanical energy that could be suddenly released as an "outburst." An outburst is a sudden, violent release of solids and high-pressure occluded gases.[14] The key word here is "occluded." Typically, the gas is trapped in tiny pockets within the crystal structure of salt or voids of an impermeable rock mass. During a change in stress conditions, these pockets can link up, resulting in a significant volume of gas—at full lithostatic pressure—immediately beneath the surface. If the pressure is sufficient, the thin layer of containment is burst, releasing the gas amid a shower of broken rock. The secondary shock wave caused by this primary burst of gas sometimes starts a chain reaction, with several million cubic feet of gas and several thousand tons of rock being ejected, resulting in voids a hundred feet or more in height [Plimpton et al. 1979].[15] This is the reason for the precautions taken at the Boulby potash mine in the United Kingdom, where the excavation is required to stay well beneath potentially gas-bearing shale formations [Lumsden and Talbot 1983].

Outbursts can be triggered by the stress redistribution that follows blasting or excavation by continuous mining machines [Lumsden and Talbot 1983]. Blasting is performed only with workers on the surface; however, continuous mining machines require an operator. This is why continuous mining machines used in domal salt mines should be operated only in areas that are known to be relatively gas-free.

WHAT EXPERIENCED MINE OPERATORS HAVE TO SAY ABOUT METHANE CONTROL

The perspective of experienced mine operators adds much to a complete understanding of what must be done to address methane problems in metal/nonmetal mines. In our discussions with operators of gassy mines, the one concern expressed by all was the need to be vigilant. Safety precautions can always be defeated by careless or foolish actions. Below are summaries of interviews with five such operators across the United States.

[14]More information on outbursts in domal salt mines is available from Iannacchione et al. [1984], Schatzel and Hyman [1984], Molinda [1988], and Grau et al. [1988].
[15]Small quantities of methane gas may also be liberated while drilling or undercutting in domal salt mines, thus the need for permissible equipment in Category II–A mines.

Dave Graham is the safety and health manager of General Chemical's trona mine in Green River, WY. This mine liberates large quantities of methane from the oil shales above and below the trona beds. Dave says that everyone knows what to do in "normal" mining operations, where continuous-reading methanometers keep track of gas levels. However, his concern is whether miners will recognize unusual and infrequent situations. Once they are aware of a hazard, they know what to do, but it may not be obvious that a hazard exists. Dave comments that "Miners can't let their guard down. They have to be constantly asking themselves, 'Will this situation create a hazardous buildup of gas?' "

Charlie Young is the plant manager of the Weeks Island Mine in New Iberia, LA, a large domal salt mine prone to gas outbursts. They blast with the mine evacuated and must test for gas remotely from the surface before sending miners back underground. Charlie concentrates on three approaches to methane control:

- *Ventilation*. The primary ventilation system must be capable of flushing out large quantities of gas if a methane outburst occurs after a remote blast, without the use of auxiliary ventilation, because the power to the mine is automatically deenergized by the mine-wide methane monitoring system.

- *Remote gas monitoring*. Remote gas monitoring depends on sensors placed close to the face line to detect gas concentrations well below the explosive limit (the sensors are sensitive to .01% methane).

- *Maintenance of permissible equipment*. Face and bench undercutting and drilling equipment, along with auxiliary face fans, must be approved by MSHA as permissible and maintained in approved condition.

Rick Steenberg is the mine manager of FMC's trona mine in Green River, WY. The mine is classified as a Category III gassy mine, so all production equipment must conform to MSHA standards of permissibility.

Rick is constantly aware of the need to make sure that methane is flushed out of the mine with adequate quantities of fresh air. Also, a comprehensive audit system designed to check the equipment for permissibility compliance has become institutionalized and has proven effective.

Jim Lekas owns and operates the ITM Mine in Vernal, UT, which produces gilsonite. Gilsonite is solid hydrocarbon resin, a black carbonaceous mass. Gilsonite mines include an additional hazard along with methane gas: the high flammability of the carbon-rich dust.

Jim emphasizes training to be alert for possible gas problems in poorly ventilated working places and to make sure that there is enough air to dilute any accumulations before hand-operated metal tools that could create sparks are used.

Ventilation is accomplished by introducing fresh outside air into the upper levels of active mining areas through surface-mounted, forced-air ventilating fans, with the pneumatic conveying system exhausting air from the lower levels back to the surface. The fans that provide the intake air and the motive force for the pneumatic conveyors are all outside of the mine. No electric equipment is used in the mine, permissible or otherwise.

Dick Heinen is the manager of mines for the Intrepid potash mines in Carlsbad, NM. The potash mines have gas within the evaporite strata and are classified as Category IV gassy mines.

The noncombustible ore is extracted and liberates a concentration of methane that is not explosive or capable of forming explosive mixtures with air based on the history of the potash mines. However, gas accumulating in possible bed separations in the roof of the mine can provide additional pressure to cause slabbing in mine intersections.

Dick insists that pressure relief holes be drilled 20–27 ft deep in the roof of every intersection. These serve both as detectors for bed separation and also as gas relief vents. The mine checks for methane gas every shift in every panel. The measured gas levels are almost always below the detection levels of the instruments. Any gas coming from relief holes is effectively diluted by the mine's ventilation system.

LOOKING FOR METHANE WHEN OPENING A NEW OR EXPANDING AN EXISTING METAL/NONMETAL MINE

From both safety and economic perspectives, when opening a new or expanding[16] an existing metal/nonmetal mine, it is critical to know whether methane will be present. For example, the presence of methane will impact ventilation design and permissible equipment purchases, two of the many items that will affect the safety and profitability of the mine. Answers can be provided by knowledge of the local geology and by gas testing.

Knowledge of the local geology. The most obvious source of information about the potential for gas in any new mine or new section of an existing mine is the geology and history of the area and any nearby mines. If mines that are geologically similar to the new mine have gas problems, then the new mine will almost certainly share in those problems.

If no mines exist in the area to allow for comparison, then other geological information should be studied. The key geological factors to look for are the presence of coal seams, carbonaceous shales, and other strata containing oil or gas production wells. All of these raise the risk of having gas in the mine. Methane originates from the decay of the carbonaceous materials inherent in coal seams, oil shales, and other carbon-bearing rocks. Methane is also embedded within the deep mantle rocks of the earth. It can be dissolved under pressure within water and other fluids and carried with them until the liquid emerges into an underground void. As the void is reached, the reduction in pressure releases the gas into the atmosphere. Methane can also remain in its gaseous form and migrate, independently of any carrier fluids, over great distances.

[16]This includes shaft excavation. For more information on controlling methane during shaft excavation, see Chapter 9.

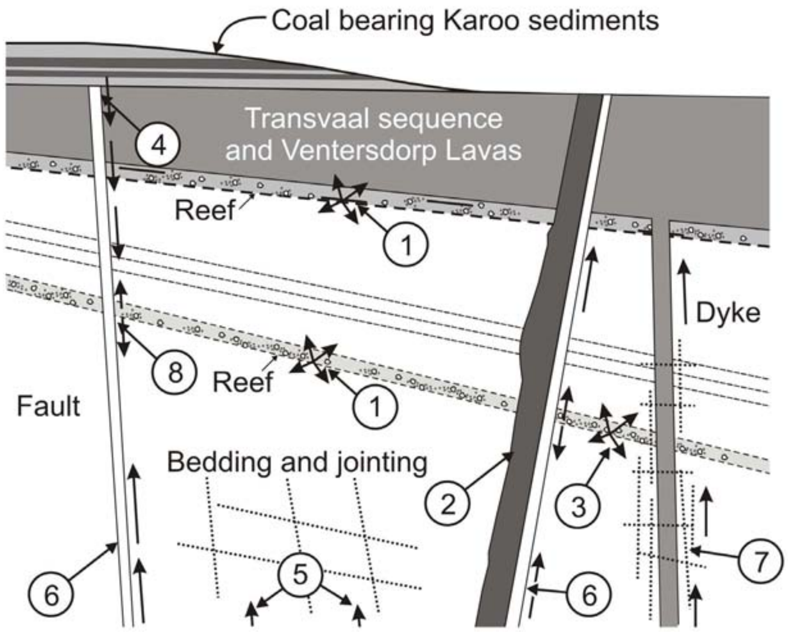

Figure 13–2.—Examples of methane emission as reported in South African metal/nonmetal mines [Cook 1998]. (*Courtesy of SIMRAC.*)

KEY:

1 - Associated with carbonaceous material in reefs.
2 - In inclusions in alkaline dykes (although unlikely in dykes generally).
3 - Thermogenic methane where dykes have heated carbon in reefs.
4 - Coal seams in overlying Karoo sediments, with transportation to Witwatersrand strata in solution in water via fault planes.
5 - General seepage of mantle methane via joints and bedding.
6 - Strong seepage of methane along major faults, which are often along dyke contacts.
7 - Collection of methane in highly jointed areas, e.g., adjacent to dykes.
8 - Seepage of methane from reef carbonaceous material into fault systems.

Figure 13–2 illustrates most of the mechanisms for methane transport in South African mines. In Figure 13–2, emission source No. 1 results from the simple decomposition of the carbonaceous material in the gold ore body (the reef),[17] whereas No. 3 requires heat to release the methane gas from the carbon in the ore body. Nos. 2, 6, and 7 are variations on the same theme, without regard to the original source of the gas. Nos. 4 and 8 represent a common origin for methane gas in metal/nonmetal mines. The methane comes from coal or other carbonaceous seams and is carried into the mine via joints and faults. In the case of No. 4, the gas is carried in solution in the hot, pressurized ground water, but No. 8 shows the gas entering the mine via direct connections, such as geologic discontinuities or exploration drillholes.

Methane can be carried in joints, faults, dykes, sills, and other geologic discontinuities. The more prevalent the discontinuities, the more permeable the rock and the greater the potential for gas storage and transportation.

[17]A “reef” is a lode or vein, a term commonly used in South Africa to describe the quartzite host rock for the flat-lying, gold-bearing formations.

Exploration drillholes can be a major conduit for gas migration. Typically, these will be drilled during the initial phases of opening up an ore body or new sections of the same ore body.[18] In at least one case in the United States, decades-old deep wells that had not been plugged properly may have provided a link between coal measures and permeable strata, which in turn funneled the gas into a major fault system. Gas subsequently entered the mine via water carried along a secondary fault that had branched off from the major fault zone.

Gas testing. Another primary task when opening up a new mine or expanding an existing mine is testing for methane gas at all stages in the exploration and development of the mine. Gas tests must be conducted at the collar of exploration drillholes[19] and at the roof of newly exposed faces. If no gas is found during those two stages, it is less likely to be present in the production phase of the mine's life. However, gas at just one drillhole or at one newly exposed face indicates a potentially larger gas problem. Immediate measures must be taken to confirm the presence of methane by laboratory analysis and to carefully sample all of the other drillholes and newly exposed faces that are part of the project.[20]

Methane can sometimes be associated with water in underground mines. Any gas bubbling from water coming from a fault zone or from pools of water collecting in the floor of the mine or tunnel should be sampled and analyzed for methane and other gases, such as carbon dioxide and hydrogen sulfide.

For mines where the presence of methane is not definitely established, Thimons et al. [1979] established a simple guideline that would enable mine personnel to evaluate the methane hazard. In their research, they measured trace methane concentrations in 53 metal/nonmetal mines, finding that mines with a return concentration exceeding 70 ppm of methane were inevitably classified as gassy.[21] Although a measurement of concentration alone is not the complete methane story, a return concentration exceeding 70 ppm should serve as an alert to the presence of gas that has not yet shown itself in other ways.

[18]In the Republic of South Africa, there has been considerable study of the occurrence of methane gas associated with gold mining in the Witwatersrand. The Chamber of Mines published a comprehensive text on mitigating gas problems entitled *Flammable Gas in Metal Mines: A Guide to Managers to Assist in Combating Flammable Gas in Metal Mines* [Association of Mine Managers 1989]. This guide contains specific sections on methane occurrence and detection, the prevention of flammable gas accumulations, ventilation systems, mining methods, equipment modifications, "hot work" permits, and the responsibilities of mine officials with regard to methane control.
[19]For more on sampling from boreholes, see Chapter 2.
[20]In addition to methane, laboratory analysis should test for other gases that may be flammable or toxic, such as ethane or hydrogen sulfide.
[21]In 1979, the MSHA classification system for metal/nonmetal mines with methane was different from the current standard. However, the triggers that lead to extra precautions (such as measurement of 0.25% or an ignition in the mine) are similar.

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APPENDIX A.—ONTARIO OCCUPATIONAL HEALTH AND SAFETY ACT R.R.O.[22] 1990, REGULATION 854 MINES AND MINING PLANTS, SECTION 35

35. (1) If a flow of flammable gas is encountered in a mine or in an enclosed building housing a diamond drill on the surface and the concentration of the flammable gas is *unknown*[23],

(a) all sources of ignition in the affected area shall be eliminated;

(b) all electrical equipment in the affected area shall be de-energized;

(c) the affected area shall be evacuated;

(d) precautions shall be taken to prevent persons from entering the affected area inadvertently;

(e) a supervisor shall be notified;

(f) the affected area shall be tested by a competent person; and

(g) the affected area shall be designated as a fire hazard area. O. Reg.[24] 236/99, s. 3.

(2) Subject to subsections (3), (4) and (5), work may resume if the concentration of flammable gas is below 1.0 per cent. O. Reg. 236/99, s. 3.

(3) If the concentration is less than 0.25 per cent and the affected area is tested periodically to ensure that the level of concentration is known, no precautions are required. O. Reg. 236/99, s. 3.

(4) If the concentration is 0.25 per cent or greater but not more than 0.5 per cent, all of the following precautions shall be taken:

1. The supervisor shall provide written instructions of any special precautions.

2. The instructions, if any, shall be communicated to the workers.

3. The affected area shall be designated as a fire hazard area.

4. The affected area shall be tested at least once per shift before work begins and, again, on release of any further flow of gas.

5. A flammable gas detector shall remain in the affected area for the purpose of continued testing. O. Reg. 236/99, s. 3.

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[22]Revised Regulations of Ontario (Canada).
[23]Emphasis ours.
[24]"O. Reg." stands for Ontario Regulation.

(5) If the concentration is 0.5 per cent or greater but not more than 1.0 per cent, all of the precautions set out in subsection (4) shall be taken and the electrical equipment, diesel engines, tools and other material used in the workplace shall be designed to function safely in a flammable gas atmosphere. O. Reg. 236/99, s. 3.

(6) If concentrations of flammable gas exceed 1.0 per cent in an area, all of the following precautions shall be taken:

1. All sources of ignition in the affected area shall be eliminated.

2. All electrical equipment in the affected area shall be de-energized.

3. All persons, other than competent persons necessary to measure the concentration of flammable gas and to make ventilation changes, shall be removed from the affected area. O. Reg. 236/99, s. 3.

(7) In mines where flammable gas is known to occur, workers who are underground or diamond drillers who are on the surface shall be advised of,

(a) the probability of encountering a flow of the gas; and

(b) the measures and procedures prescribed in this section. O. Reg. 236/99, s. 3.

(8) For the purposes of this section, the concentration of flammable gas means the percentage, by volume, of flammable gas in the general atmosphere. O. Reg. 236/99, s. 3.